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Conservation agriculture and nitrogen management in maize–wheat cropping system: effect on growth, productivity and economics of wheat

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Abstract

A study was conducted at ICAR-Indian Agricultural Research Institute, New Delhi to assess the effect of six combinations of tillage and crop establishment techniques, *i.e.* conventional tillage-flat-bed (CT-F), CT-raised-bed (CT-B), zero tillage-flat-bed with crop-residue (ZT-F+R) and without crop-residue (ZT-F), ZT-raised-bed with crop residue (ZT-B+R) and without crop-residue (ZT-B) in combination of four levels of fertilizer-nitrogen (N; 0, 60, 120 and 180 kg N/ha) on growth, yield and economics of wheat (*Triticum aestivum* L. emend. Fiori & Paol) in conservation agriculture based maize (*Zea mays* L.)-wheat cropping system. The performance of the wheat in terms of growth, yield and net returns was observed statistically similar under different tillage and establishment techniques but it was differed significantly ($p \leq 0.05$) due to different levels of N. Crop-residue applied treatments (ZT-F+R/ZT-B+R) improved the grain and straw yields over without crop-residue applied ZT (by 5.2 and 3.6% under flat-planting; and 7.7 and 4.1% under raised-bed planting systems, respectively) and CT practices (by 12.0 and 5.4% under flat-planting and 8.1 and 3.4% under raised-bed planting systems, respectively). The ZT technology reduced the cost of cultivation by 9.8% and improved the net profits by 9.0% over the CT practices. Further, recycling of crop residue under ZT practices (ZT-F+R/ZT-B+R) not only produced the maximum grain yield (8.0-12.0% higher) but also generated either equal or higher net profits over the CT practices. The growth, yield attributes, grain yield, straw yield and net returns were increased significantly up to 120 kg N/ha, though the maximum values of most of these parameters were recorded at 180 kg N/ha. Therefore, it can be concluded that ZT practices along with crop residues and 120 kg N/ha could be adopted to make the wheat cultivation more remunerative and sustainable.

Keywords: Conservation agriculture, economics, nitrogen, productivity, wheat

Introduction

Wheat (*Triticum aestivum* L. emend. Fiori & Paol) is playing an important role in the food and nutritional security of India as it is the second most important staple food crop after rice and contributing about 35% in the national food grain production. The traditional wheat production system entailing intensive tillage, over and indiscriminate use of water and fertilizer resources has increased the productivity tremendously but has also resulted the deteriorated soil health, depleted ground water table and environmental pollution simultaneously (Sharma *et al.*, 2012; Jat *et al.*, 2013) [26, 14]. These practices along-with over increasing input-costs have made the wheat cultivation input in-efficient, uneconomical and unsustainable (Jat *et al.*, 2019a; Choudhary and Behera, 2020) [13, 6]. Soil tillage is one of the fundamental agro-technical operations in agriculture because of its influence on soil properties, environment and crop growth. Since continuous soil tillage strongly influence the soil properties, it is important to apply appropriate tillage practices that avoid the degradation of soil structure, maintain crop yield as well as ecosystem stability. Intensive conventional tillage (CT) practices have not only negatively influenced the soil properties but have also reduced the profitability (Choudhary and Behera, 2014; 2019; Jat *et al.*, 2019b) [3, 5, 16]. Tillage practices contribute greatly to the labour cost and energy-use in field crop production systems resulting in to lower economic returns and poor resource-use efficiency (Choudhary and Behera, 2013; 2019; Choudhary *et al.*, 2020) [2, 5, 7]. In addition to this, left over residue of crops in CT-based systems is usually burnt which results in loss of valuable biomass and also

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creates the environmental pollution (Gathala *et al.*, 2011; Jat *et al.*, 2013; Choudhary *et al.*, 2017) [10, 14, 4]. Further, the efficiency of input-use, viz. water, fertilizers, herbicides and others depend on tillage and crop establishment practices. It is therefore essential that the soil environment be manipulated suitably for ensuring a good crop and to achieve higher resource-use efficiency. Therefore, to minimize the production cost and reduce the environmental footprints of agro-inputs, the conservation agriculture (CA) has been advocated by the many researchers as a climate resilient, sustainable and profitable production system of the crops (Jat *et al.*, 2013; Jat *et al.*, 2019c) [14, 17]. The minimal soil movement by reduction in tillage intensity and retention of crop-residues on the soil surface along with crop rotations and diversification to economically benefit the farmers are the key principles of CA (Verhulst *et al.*, 2011) [29]. Now days, CA systems have gained importance due the need of farmers to reduce variable cultivation cost, as major portion of production cost is being utilized for field preparation and crop establishment. The zero-tillage (ZT) method of sowing is cost effective, energy efficient and beneficial to environment as compared to CT practices of crop production (Filipovic *et al.*, 2006; Jat *et al.*, 2019c) [9, 17].

Nitrogen (N) is needed in large amount and provision for an adequate supply of N throughout the growing season is necessary for realizing the potential yields (Singh *et al.*, 2009) [28]. As Indian soils are universally deficient in N and adequate supply of the N to crop under CA system should be ensured to achieve the potential benefits of CA. It has also been reported that cereal crops exhibit reduced yields during the early phase of adoption of CA because of lesser N availability due to slower soil N mineralization, and greater immobilization, denitrification and NH_3 volatilization losses than the CT systems (Patra *et al.*, 2004) [22]. All these complexities with N under CA indicate the need for more research to understand the response of N to wheat under CA systems so as optimal supply of N could be ensured. Accordingly, this study was conducted with the objective to investigate the effect of conservation agricultural and N management practices on productivity and profitability of wheat in CA-based maize-wheat cropping system.

Materials and Methods

Field experiments were conducted at the ICAR-Indian Agricultural Research Institute, New Delhi (28.4° N latitude, 77.1° E longitude and 228.6 m above mean sea level) during the winter seasons (November to April) of 2009-10 and 2010-11. At the start of the experiment, the soil was sandy loam in texture had 1.57 g/cm³ bulk density, 17.48% (w/w) field capacity and 1.26 cm/hr infiltration rate. The organic carbon, KMnO_4 oxidizable N, 0.5 N NaHCO_3 extractable P, 1.0 N NH_4OAc exchangeable K, pH and electrical conductivity of the soil were observed 0.37% 147.6 kg/ha, 11.8 kg/ha, 235.1 kg/ha, 7.5 and 0.31 dS/m, respectively. The mean annual rainfall of the site is 672 mm out of which more than 80% generally occurs during the monsoon season (July-September) with mean annual evaporation 850 mm.

The treatments were accommodated in split-plot design with three replications in a fixed layout. There were six main-plot treatment combinations of different tillage and crop establishment techniques: conventional tillage-flat (CT-F), zero tillage-flat (ZT-F), conventional tillage-bed (CT-B), zero tillage-bed (ZT-B), ZT-flat with residue (ZT-F+R) and ZT-bed with residue (ZT-B+R). Four levels of nitrogen (N) viz., 0, 60, 120 and 180 kg/ha were accommodated in sub-plots.

The CT consisted of two pass of a disc harrow, followed by two pass of cultivator with planking in the last pass. Raised beds (fresh bed) were made with a bed planter which made beds at distance of 67.5 cm from bed to bed with a bed height of 8". The ZT consisted of no-tillage with minimum soil disturbance and one pass of ZT seed drill for sowing of crop. In ZT-beds (permanent beds) one pass of bed planter was made for sowing of crop and reshaping of beds. The fresh and permanent raised beds were of 67.5 cm width having 37.5 cm top and 30 cm furrow, which was used for irrigation purposes. The wheat crop (var. PBW 550) was sown at a spacing of 18 cm from row to row with 100 kg seed/ha in flat planting, while three rows of wheat crop was established on top of the raised beds by keeping plant spacing of 5 cm. The chopped residue of the previous maize crop was applied at 5.0 t/ha as per the treatments. Before sowing, weeds were controlled using tank mix paraquat + glyphosate (each 0.5 kg a.i./ha) in ZT practices. In standing wheat crop, tank mix solution of isoproturon (75 WP at 1 kg a.i./ha) and 2,4-D sodium salt (80 WP at 0.5 kg a.i./ha) was applied to control grassy as well as broad leaf weeds after 35 DAS. Full dose of P (26.2 kg/ha) and K (33.3 kg/ha) applied at the time of sowing in both the crops. Full dose of P (26.2 kg/ha) and K (33.3 kg/ha) applied at the time of sowing, while, N was applied in two equal splits (one at sowing and other after first irrigation) as per the treatments. The other standard and recommended practices of CA and CT were followed to harvest good crops.

Five plants from sampling rows were randomly selected and tagged for all the periodic height observations and their height was measured from the ground level to the tip of flag leaf at 30, 60 and 90 days after sowing and up to tip of ear at harvest. In flat sown wheat, 0.25 m² areas was selected after leaving the first row from either side of the plot and the same area was selected from second bed of plot from the bed sown plots for the measurement of dry matter accumulation. The samples were sun dried first and then in an oven at 65°C till the constant weight arrived. The accumulated dry matter (as g/m²) was divided with the days to obtain the crop growth rate (CGR, g/m²/day) between 0-30, 30-60 and 60-90 DAS. Those seeds which were emerged from the soil after their germination were counted and germination count expressed as number/m². Number of tillers were counted from 0.25 m² area randomly from four spots in the net plot, averaged and expressed as number of tillers/m² area, while ear bearing tillers in the same area were regarded as effective tillers. Total biomass of each net plot was harvested, weighed and threshed after drying. The grains were cleaned and sun dried for 3 to 4 days and weight was determined in t/ha at 14% moisture content. The weight of straw was computed by subtracting the weight of grain from total dry matter yield of each net plot and expressed in t/ha. The economics of cultivation was worked out on the basis of prevailing market price of produce and cost of inputs. Net returns were estimated by deducting the total cost of cultivation from gross returns. Price of wheat produce was ₹ 11.00 and 11.50 per kg grain and ₹ 1.0 kg/straw during 2009-10 and 2010-11, respectively.

Analysis of variance was used to determine the effect of each treatment. When F ratio was significant, a multiple mean comparison was performed using Fisher's LSD Test ($p \leq 0.05$ probability level). The data were analyzed by two-way ANOVA technique using the PROC MIXED procedure of SAS package (ver. 9.3).

Results

Crop growth

The plant height and crop growth rate (CGR) were observed statistically similar under different tillage and crop establishment techniques at all the growth stages of wheat during both the years of study (Fig. 1A & 1B and Table 1). However, the maximum values of these growth parameters were recorded under crop residue applied ZT treatments (ZT-F+R/ ZT-B+R), while the minimum values were recorded under CT practices (CT-B/CT-F). In general, plant height was increased about 1.53, 1.60 and 0.03 times at 60, 90 DAS and

maturity over the 30, 60 and 90 DAS, respectively. The CGR was increased gradually with the advancement of growth stages and it attained the maximum values at 60-90 DAS interval during both the years. However, both plant height and CGR were significantly influenced due to different levels of N during both the years. At all the crop growth stages, these parameters were increased significantly with each successive level of N up to 120 kg during both the years. No significant increase in these growth parameters was observed at 180 kg N/ha over the 120 kg N/ha.

Fig 1: Effect of tillage and crop establishment techniques (A & B), and N levels (kg/ha; C & D) on plant height (cm) of wheat

Table 1: Effect of tillage and crop establishment techniques, and N levels on crop growth rate (g/m²/day) of wheat

Treatment	0-30 DAS		30-60 DAS		60-90 DAS	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
Tillage and crop establishment						
CT-F	1.33	1.37	3.52	3.60	17.58	18.22
CT-B	1.23	1.40	3.51	3.57	17.22	17.65
ZT-F	1.32	1.55	3.71	3.57	17.88	18.45
ZT-B	1.34	1.39	3.56	3.63	17.56	18.10
ZT-F+R	1.34	1.61	3.84	3.64	18.81	19.35
ZT-B+R	1.35	1.58	3.66	3.52	18.09	18.60
SEm±	0.037	0.067	0.112	0.122	0.697	0.618
LSD ($p \leq 0.05$)	NS	NS	NS	NS	NS	NS
Nitrogen levels (kg/ha)						
0	1.07	1.15	3.40	3.35	13.98	14.14
60	1.31	1.48	3.60	3.59	17.40	17.84
120	1.42	1.64	3.76	3.71	19.74	20.41
180	1.47	1.67	3.78	3.71	20.32	21.18
SEm±	0.027	0.044	0.051	0.069	0.397	0.418
LSD ($p \leq 0.05$)	0.078	0.127	0.145	0.198	1.140	1.198

Crop development and yield attributes

The germination counts and number of days taken to 50% flowering were not influenced significantly due to tillage and crop establishment techniques during both the years (Table 2). However, flowering was recorded 2-3 days earlier during 2009-10 than 2010-11. The maximum germination counts were recorded under crop residue applied ZT treatments (ZT-F+R/ ZT-B+R), while the minimum values were recorded under CT practices (CT-B/CT-F). Germination counts did not differ significantly, but the number of days taken to 50% flowering was influenced significantly due to different levels of N during both the years. The maximum period for flowering was recorded with 180 kg N/ha, while minimum days with treatment received no-N. The effect of different tillage and crop establishment techniques on the tillers/m² and effective tillers/m² of wheat were also observed non-significant during both the years (Table 2). However, the maximum values of these parameters were recorded under ZT-F+R, while the minimum values under CT-F. These

parameters were influenced significantly due to different levels of N during both the years. The tillers/m² and effective

tillers/m² were increased significantly with each successive increase in N level up to 120 kg/ha during both the years.

Table 2: Effect of tillage and crop establishment techniques, and N levels on yield attributes of wheat

Treatment	Germination counts/m ²		Days to 50% flowering		Tillers/m ²		Effective tillers/m ²	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
Tillage and crop establishment								
CT-F	184.4	210.6	85.83	88.67	440.4	441.8	435.2	431.4
CT-B	176.8	248.1	83.50	86.33	450.0	491.5	425.8	454.0
ZT-F	190.9	226.2	85.50	88.33	477.9	475.8	463.8	467.0
ZT-B	184.4	242.0	84.67	87.50	452.3	488.2	429.0	466.1
ZT-F+R	197.9	235.9	88.08	88.92	487.4	491.5	478.7	475.3
ZT-B+R	187.8	259.1	83.08	87.92	465.3	486.7	453.3	474.6
SEm±	7.505	9.461	1.363	0.896	10.67	14.71	12.77	15.26
LSD ($p \leq 0.05$)	NS	NS	NS	NS	NS	NS	NS	NS
Nitrogen levels (kg/ha)								
0	184.4	231.0	83.11	85.94	418.7	419.1	401.1	404.8
60	187.7	235.9	84.78	87.61	461.4	473.1	444.5	461.6
120	187.1	239.9	86.00	88.83	481.6	506.7	467.0	488.7
180	189.1	241.1	86.56	89.39	487.2	518.1	477.8	490.4
SEm±	3.195	7.001	0.879	0.525	6.333	10.54	7.447	9.126
LSD ($p \leq 0.05$)	NS	NS	2.522	1.505	18.16	30.24	21.36	26.17

Crop yields

The grain and straw yields of wheat were remained statistically similar due to different tillage and crop establishment technique in both the years of study (Table 3). However, irrespective of the treatments, the grain and straw yields were observed marginally higher during 2010-11 than 2009-10. Nevertheless, the maximum grain and straw yields were recorded under ZT-F+R closely followed by ZT-B+R, while the minimum yields were obtained in CT treatments (CT-F/CT-B) during both the years. Crop-residue applied treatments (ZT-F+R/ZT-B+R) improved the grain and straw yields over without crop-residue applied ZT (by 5.19 and 3.60% under flat-planting; and 7.66 and 4.14% under raised-bed planting systems, respectively) and CT practices (by 12.0 and 5.36% under flat-planting and 8.09 and 3.35% under raised-bed planting systems, respectively). Further, ZT-F registered 6.39 and 1.70% higher grain and straw yields over the CT-F, respectively. Moreover, the flat-planting technique of crop establishment improved the grain yield over the raised-bed planting by 6.08% under ZT and 3.64% under ZT+R practices, respectively. Grain and straw yields of wheat were significantly influenced due to different levels of N. The values of these parameters were increased significantly with each successive increase in N levels from 0 to 120 kg/ha. However, highest values were obtained at 180 kg N/ha, which was significantly higher than 0 and 60 kg N/ha, but it remained statistically similar with 120 kg N/ha. The interaction effect of different tillage and crop establishment techniques and N levels on yield performance of wheat was found non-significant.

Economics

Data pertaining to cost of cultivation and net returns of wheat has been presented in Table 3. The minimum cost of cultivation was recorded under ZT-B (16.54×10^3 and 15.30×10^3 ₹/ha), while the maximum was registered under ZT-F+R (22.16×10^3 and 20.84×10^3 ₹/ha) during both the years. It further revealed that the ZT technology has reduced the cost of cultivation by 8.5 and 11.2% over the CT practices under flat-planting and raised-bed planting systems, respectively. The net returns were found statistically similar under different tillage and crop establishment techniques. However, the maximum net returns were obtained under ZT without residue (ZT-F/ZT-B) which was closely followed by ZT with residue (ZT-F+R/ZT-B+R) -B, while least values of net returns were registered under CT practices (CT-F/CT-B) during both the years. Further, ZT treatments improved the net returns by 11.6 and 6.4% over the CT practices under flat-planting and raised-bed planting systems, respectively. Though, recycling of high value crop-residues increased the cost of cultivation substantially, even so it improved the net returns by 5.3-5.7% (ZT-F+R) over the CT practices. The cost of cultivation was increased with each increase in N levels, which was recorded the minimum at the control and the maximum at 180 kg N/ha. Net returns were influenced significantly due to different levels of N during both the years. Net returns were also increased with increase in N levels from 0 to 180 kg N/ha, but the significant difference was observed only up to 120 kg N/ha.

Table 3: Effect of tillage and crop establishment techniques, and N levels on yield performance and economics of wheat

Treatment	Grain yield (t/ha)		Straw yield (t/ha)		Cost of cultivation ($\times 10^3$ ₹/ha)		Net returns ($\times 10^3$ ₹/ha)	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
Tillage and crop establishment								
CT-F	3.784	3.782	5.287	5.649	18.36	17.04	31.20	34.93
CT-B	3.689	3.875	5.253	5.788	18.54	17.30	29.92	35.94
ZT-F	3.945	4.011	5.315	5.806	16.86	15.54	34.51	39.30
ZT-B	3.725	3.868	5.234	5.724	16.54	15.30	32.29	37.77
ZT-F+R	4.238	4.236	5.623	5.899	22.16	20.84	32.89	36.72
ZT-B+R	4.050	4.125	5.674	5.738	21.84	20.60	31.22	35.44
SEm±	0.145	0.116	0.219	0.213	-	-	1.70	1.31
LSD ($p \leq 0.05$)	NS	NS	NS	NS	-	-	NS	NS

Nitrogen levels (kg/ha)								
0	2.779	2.897	4.070	4.030	17.46	16.06	19.21	23.30
60	3.953	4.080	5.395	5.820	18.67	17.35	32.90	38.30
120	4.369	4.407	5.950	6.525	19.58	18.34	37.40	42.13
180	4.520	4.548	6.176	6.695	20.49	19.33	38.49	43.01
SEm±	0.082	0.091	0.119	0.122	-	-	0.85	1.03
LSD ($p \leq 0.05$)	0.236	0.260	0.343	0.351	-	-	2.44	2.96

Discussion

Crop growth

Germination of crop to establish a good plant stand is an important parameter for performance, which is mainly governed by tillage and crop establishment techniques since it has direct impact on it. Germination counts of wheat were similar under different tillage and crop establishment techniques; this was might be due to good availability of soil moisture under all the tillage and crop establishment techniques. Marginally higher, uniform and 2-3 days early seed germination under the ZT than CT due to intact contact of the seeds with soil and moisture where soil was not disturbed much; this could be reason for this early vigour. Similar kind of results has also reported by McMaster *et al.* (2002) [21]. The growth parameters of wheat crop were similar under different tillage and crop establishment techniques. However, marginally higher values of growth parameters were recorded during 2010-11 than 2009-10, due to better crop establishment of crop resulted due to congenial weather conditions at the time of sowing. Comparatively higher values of growth parameters under ZT and residue recycled practices might be due to better soil health and micro-environment created by continuous adoption of these environment friendly and resource conserving practices. Yadav *et al.* (2005) [30] also reported marginally higher growth parameters under ZT than CT. Flat-planting of wheat resulted the higher values of growth parameters than raised bed-planting might be due to water stress as created by low soil moisture content in the top of the bed. Ram (2006) [23] reported that more soil temperature under beds than flat planting leads to lower soil moisture and poor growth of the crop. Being the cereal, wheat is a heavy feeder of all essential nutrients in general and that of N in particular, so application of N resulted in significantly taller plants with increased values of CGR. The overall improvement in growth of wheat with the addition of N could be ascribed to its pivotal role in several physiological and biochemical processes (Kibe *et al.*, 2006) [18].

Crop development and yield attributes

Recycling of residue under ZT treatments resulted similar or higher values of yield attributes of wheat than the CT practices might be due to prevalence of favourable soil moisture, moderated soil temperature, and improved soil fertility due to constant supply of nutrients through mineralization from the decomposing crop residues. Yadav *et al.* (2005) [30] reported that ZT led to improvement in growth and yield attributes, viz. plant height, effective tillers, grains/ear and 1000- grain weight due to better establishment of plants as a result of less weed competition under ZT. Jat (2010) [15] also reported the higher values of yield attributes under residue applications with higher doses of N fertilizers. The superiority of yield attributes of wheat with the increased levels of N might be due to benefit derived by the crops during vegetative growth period from a heavier dose of top dressing of fertilizer N along with basal application. Kumar *et al.* (2007) [19] reported that yield attributing characters of

wheat, spikes/m row and grains/spike enhanced significantly with each increase in N level up to 150 kg N/ha.

Crop yields

The grain and straw yields of wheat were similar under different tillage and crop establishment techniques. In the first 5 years of the experimentation, no significant differences in wheat yield were found between different tillage management systems (Sayre *et al.*, 2005) [25]. However, flat-planting of wheat was resulted marginally higher grain and straw yields than bed-planting might be due to low soil moisture content in the top of the bed. Sharma *et al.* (2002) [27] reported that, there are some situations where the performance of wheat on beds has been inferior to that on conventional tillage flats due to reduced tillering during vegetative stage due to water deficit stress in sandy loam soil. Ram (2006) [23] reported that more soil temperature under beds than flat planting leads to lower soil moisture and poor growth of the crop. Yadav *et al.* (2005) [30] reported that significantly higher (7.7%) yield of wheat with ZT in comparison to CT was mainly attributed to increase in effective tillers, grains/ear and 1000- grain weight in ZT. However, crop-residue applied treatments (ZT-F+R/ZT-B+R) resulted either similar or higher values of yields than CT and ZT without residue might be due to moderated soil temperature, improved soil moisture and soil fertility. Ram *et al.* (2010) [24] reported higher yields under ZT with residue due to the cumulative effects of higher light interception more dry matter production, low soil and canopy temperature, more soil moisture, tillers, grains/ear and 1000-grain weight than no-residue application under ZT and CT practices. Bakht *et al.* (2009) [11] reported that on an average, crop residue incorporation increased the wheat grain yield by 1.31 times and straw yield by 1.39 times. The increasing levels of N significantly influenced the grain and straw yields of wheat which might be due to the enhanced vegetative growth characters like plant height, dry matter production and cumulative effect of all the yield attributes. Wheat is nutrient exhaustive crop, therefore it responded well to the higher levels of N (120 kg/ha). Yadav *et al.* (2005) [30] reported that application of N up to 150 kg/ha significantly increased the grain yield of wheat. They further reported that the increase in grain yield was 12.3 and 17.3% higher with 150 and 180 kg/ha, respectively, over 120 kg N/ha.

Economics

The higher cost of production under CT practices due to more number of tillage operations have done and more labour cost involved in cultural operations like manual weeding. Tillage practices contributed greatly to the labour cost in any crop production system resulting to lower economic returns (Labios *et al.*, 1997 [20]; Choudhary and Behera, 2019 [5]). Fresh raised-bed preparation also contributed to higher cost of productions in CT practices, but here the difference is only marginal because cost involved in irrigation water and its application was saved under bed-planting system. Two cm irrigation water was saved during the each irrigation under bed-planting that has compensated the cost involves in bed

preparation. The higher cost of production during 2009-10 than 2010-11 was also due to the saving in irrigation water in the later year. During 2010-11, a good amount of rainfall as well its distribution was occurred during the crop growing season that leads to low irrigation demands. Lower cost of production under ZT than CT practices due to no-tillage operations, saving of money in weed control practices due to herbicide application, which were less costly than manual weeding and labour cost saving involved in various cultural operations. The use of ZT significantly reduces energy costs, mainly by reducing tractor costs associated with conventional methods (Erenstein and Farooq, 2009) [8]. Jat *et al.* (2005) [13] also reported that cost of cultivation was minimum (US\$ 279/ha) under FIRB followed by NT and maximum (US\$ 375/ha) under CT mainly because of difference in cost of tillage and irrigation water. The higher net returns recorded under ZT than CT practices was due to lower cost involved in sowing and other crop management practices. The highest net returns recorded under ZT-F was due to comparatively better yield performance, saving of costs involved in tillage, weed management and other crop management practices. This was in agreement with the findings of Zentner *et al.* (2002) [31]. Jat *et al.* (2005) [13] also reported higher net returns from wheat under ZT compared to FIRB and CT. Residue applied treatments exhibited higher cost of production due to higher prices of residue. Though, recycling of high value crop-residues increased the cost of cultivation substantially, even so it improved the net returns over the CT practices, indicated that ZT with residue could be successfully adopted to improve the soil health and crop productivity. The cost of cultivation has increased linearly with increase in N levels from 0 to 180 kg/ha due the cost of N fertilizers. Whereas, Net returns have improved only up to 120 kg N/ha, indicates that the additional 60 kg N/ha applied for N level 180 kg/ha could not enhanced the grain and straw yields significantly over 120 kg N/ha which might be lost in soil in different forms.

Conclusion

The performance of wheat in terms of growth, yield attributes and economics was found superior under ZT practices with or without crop residues over the CT practices. It shows good sign of energy conservation without compromising in the yield as well as profitability. The ZT technology reduced the cost of cultivation by 9.8% and improved the net profits by 9.0% over the CT practices. Further, recycling of crop residue under ZT practices (ZT-F+R/ZT-B+R) not only produced the maximum grain yield (8.0-12.0% higher) but also generated either equal or higher net profits over the CT practices. Optimum supply of N (120 kg/ha) was found crucial in realising the higher yield and profitability. Therefore, it can be concluded that ZT practices along with crop residues and 120 kg N/ha could be adopted to make the wheat cultivation more remunerative and sustainable.

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